Soaring Flight Tactics and Navigation Strategies of Migrating Monarch Butterflies

David Gibo
Dept. of Zoology
University of Toronto

Orley R Taylor
Jim Lovett, Dana Wilfong, and
Cathy Walters
of
Monarch Watch
University of Kansas

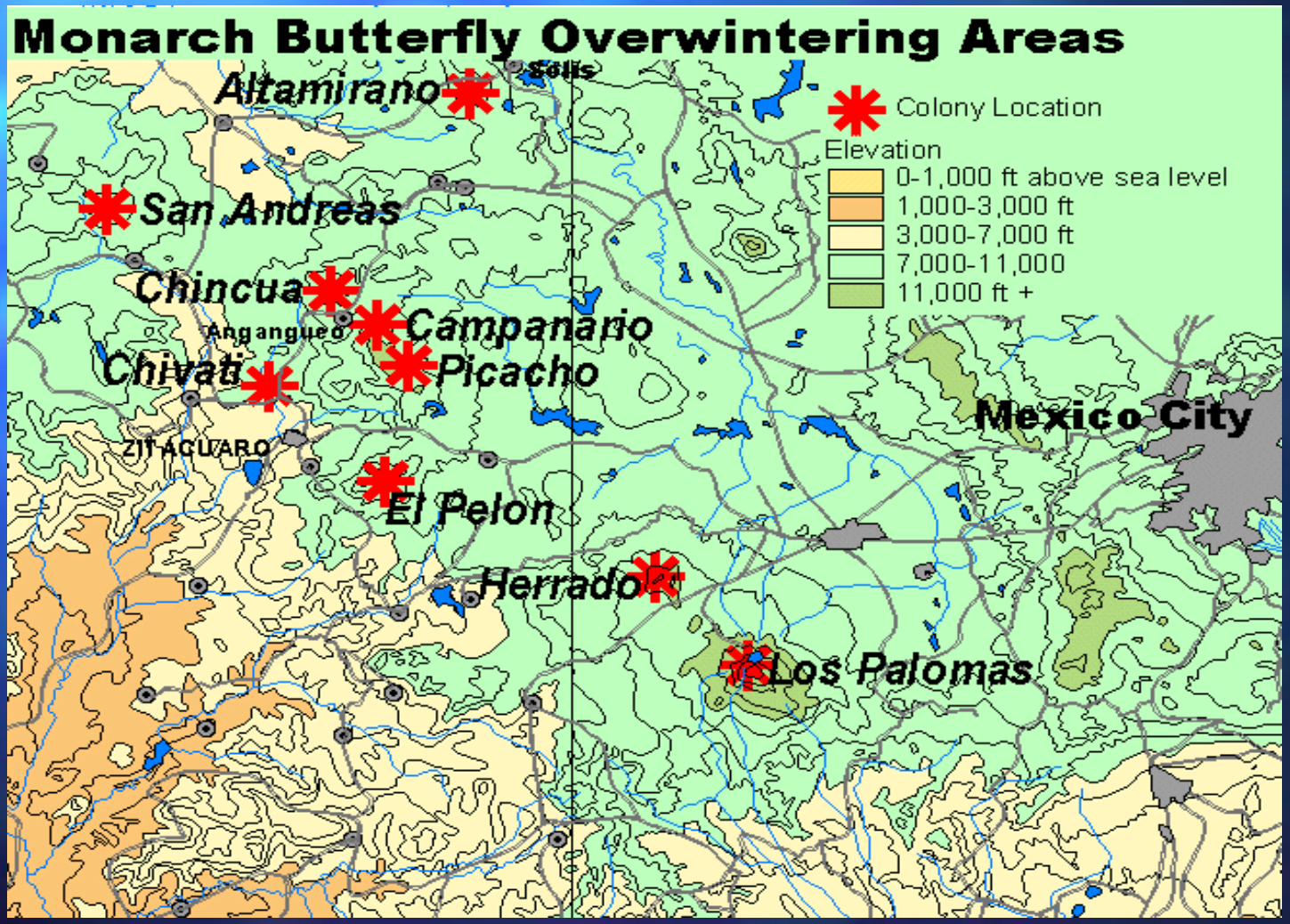
Wayne Wolf
John Westbrook
of
USDA/ARS, Texas A&M

Journey North
Annenberg/CPB

The Player: *Danaus plexippus*

The Arena: North America

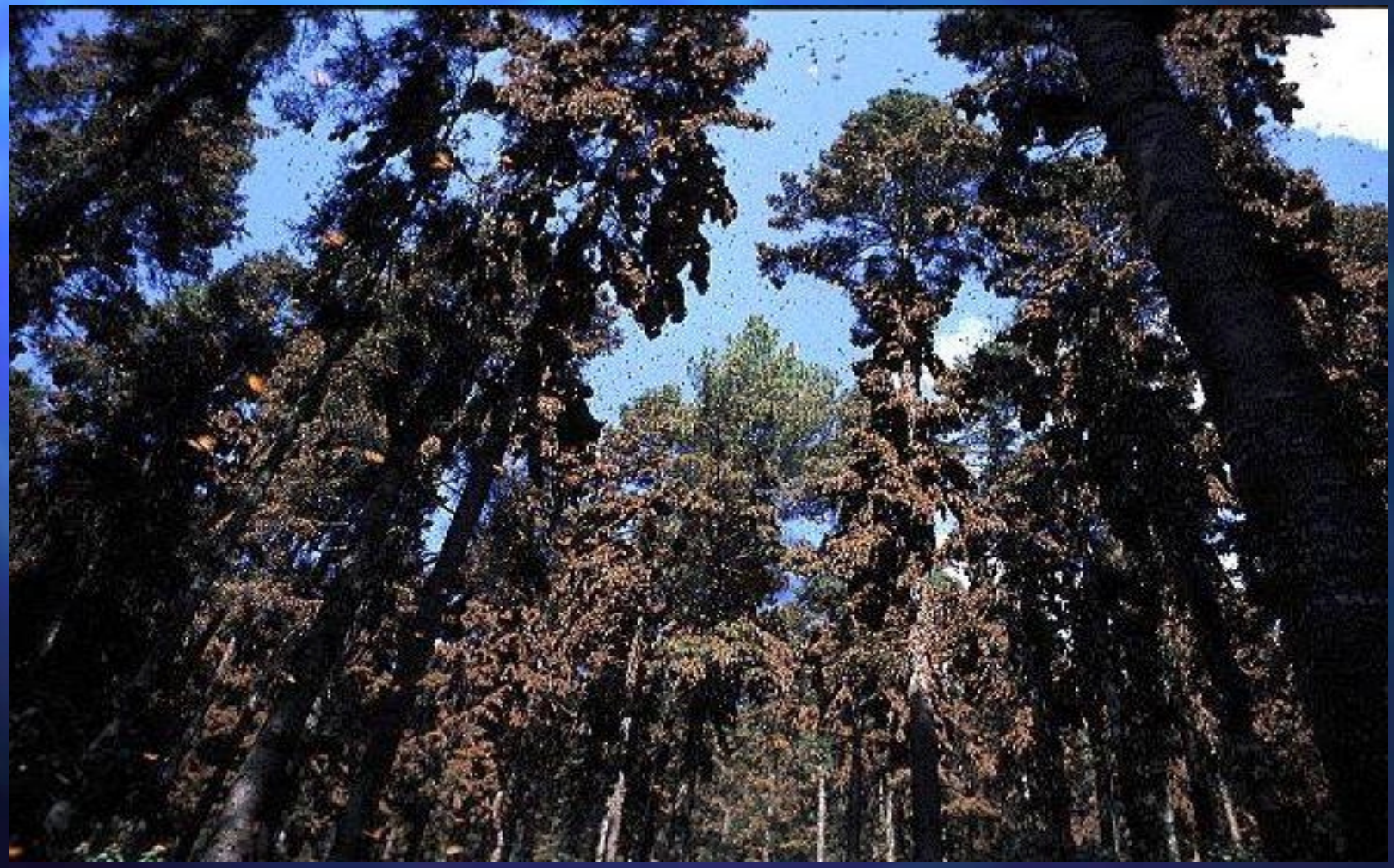
The goal: Overwintering Sites



The Start: Mainly North of 40°

Stopovers Along the Way

Overwintering Sites



Overwintering Sites

Overwintering Sites

Wing Tagging Studies

Suggested Routes

How Do They Do It?

Migrating by Soaring Can Only Be A Partial Answer

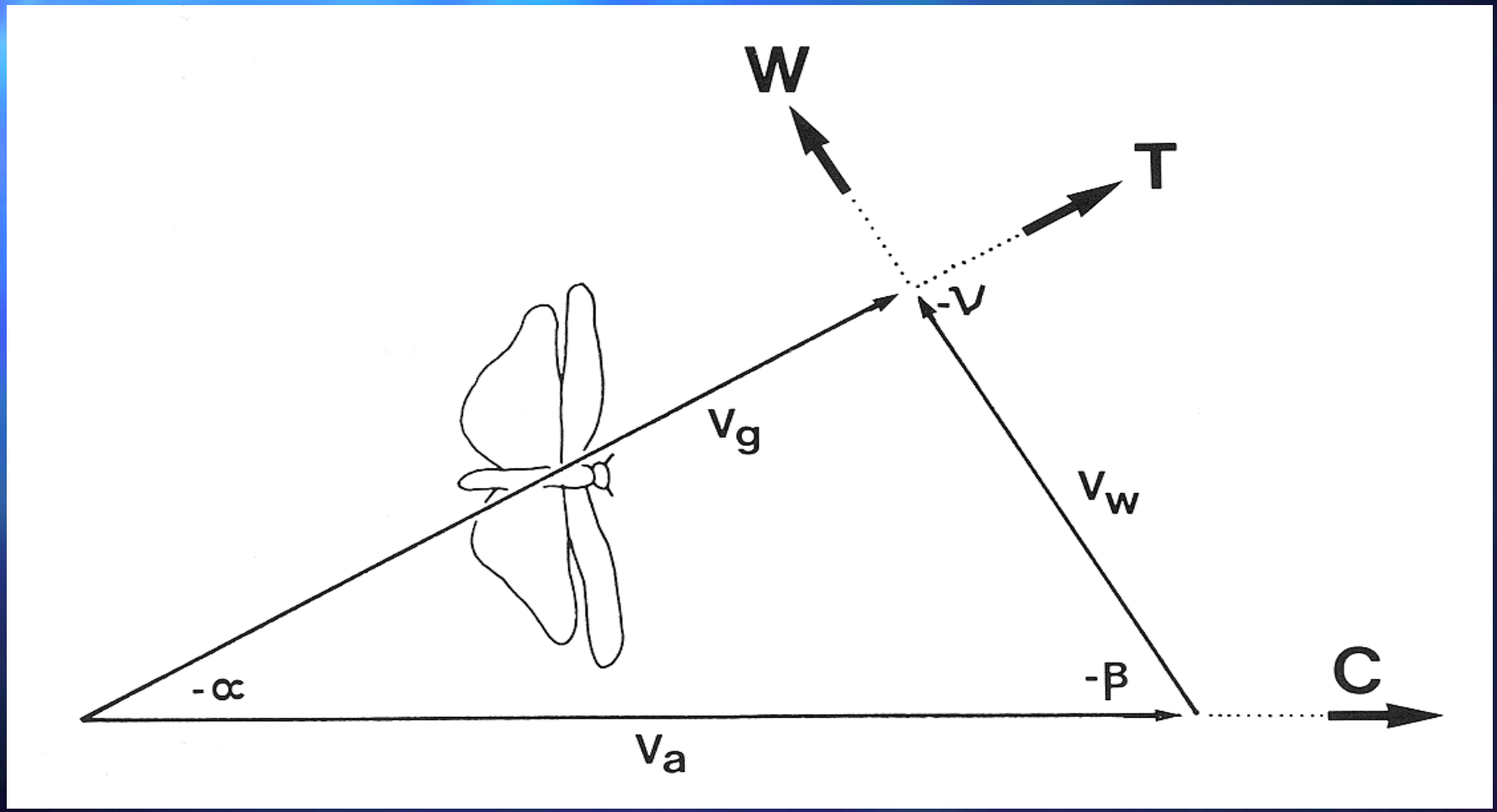
Limitations of Monarch Butterflies (flight)

- Small size: Wingspan = 11 cm, body = 3.5 cm, mass = 550 mg
- Low airspeed: 5 m/s for cruising flight, 3.3 m/s for gliding and soaring flight
- Low glide ratio: Best L/D = 4:1; Limited ability to search for thermals

Limitations of Monarch Butterflies (flight)

- Small fuel supply: 125 mg of lipid; Migrants Start with only 25 mg of lipid
- Limited range: 125 mg = 800 km in cruising flight; Need 4000 km
- Temperature restrictions: Prefer to fly at 16°C - 25°C; Will accept 8°C - 30°C

Limitations of Monarch Butterflies (wind drift)



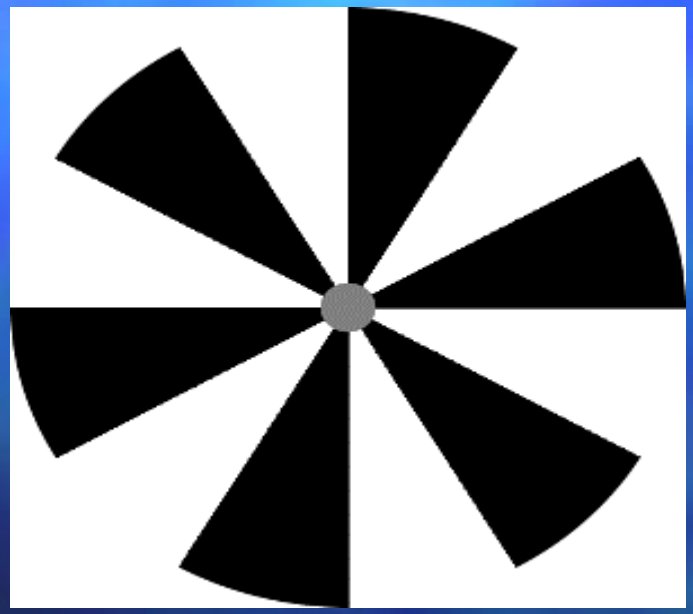
Limitations of Monarch Butterflies (navigation)

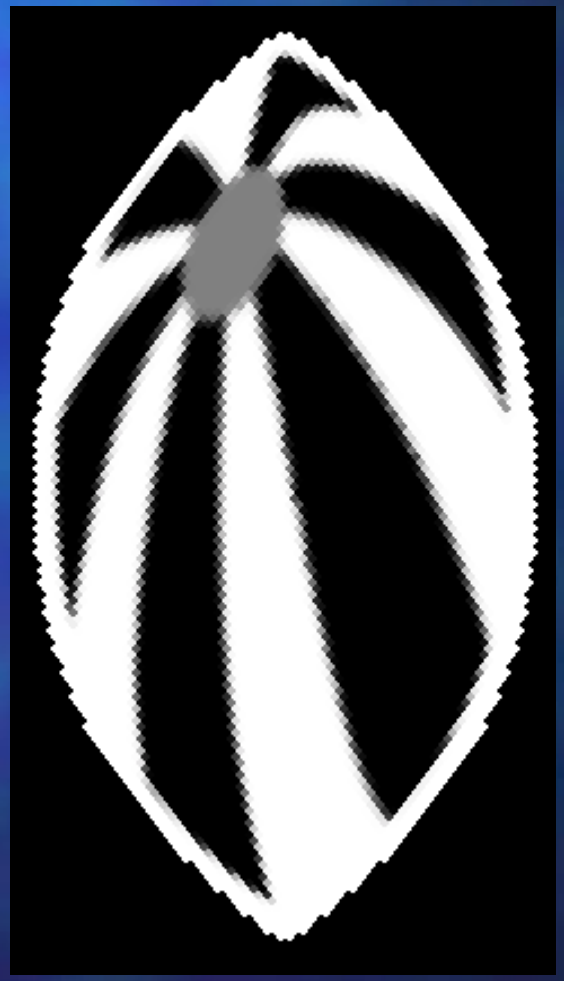
- No map sense: Unaware of position with respect to overwintering sites
- Poor memory: Cannot learn route or improve flight tactics
- No mental image of surroundings: Unable to plan route or take shortcuts

Limitations of Monarch Butterflies (general)

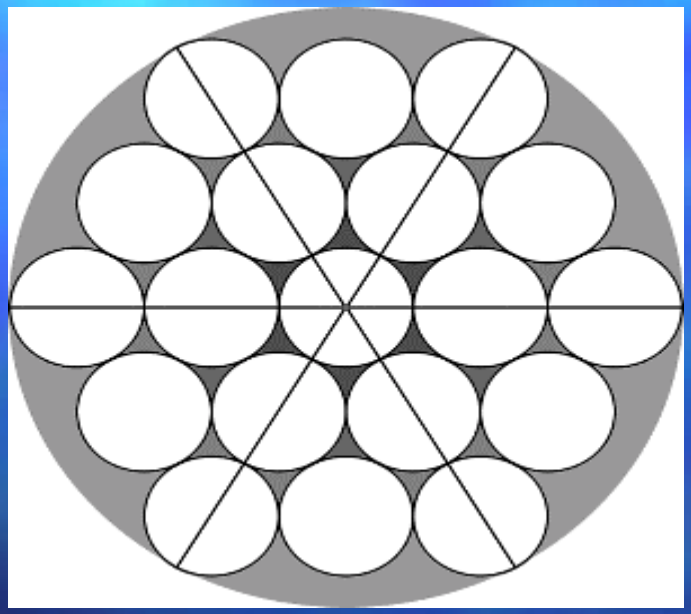
- Diurnal: Night flying may occur if caught out over large bodies of water
- Deaf: Although moths have ears to hear bats, almost all butterflies lack ears
- Poor Vision: Visual acuity is about 1°; Very limited at pattern recognition

Insect Vision (B-EYE): An Abstract Flower

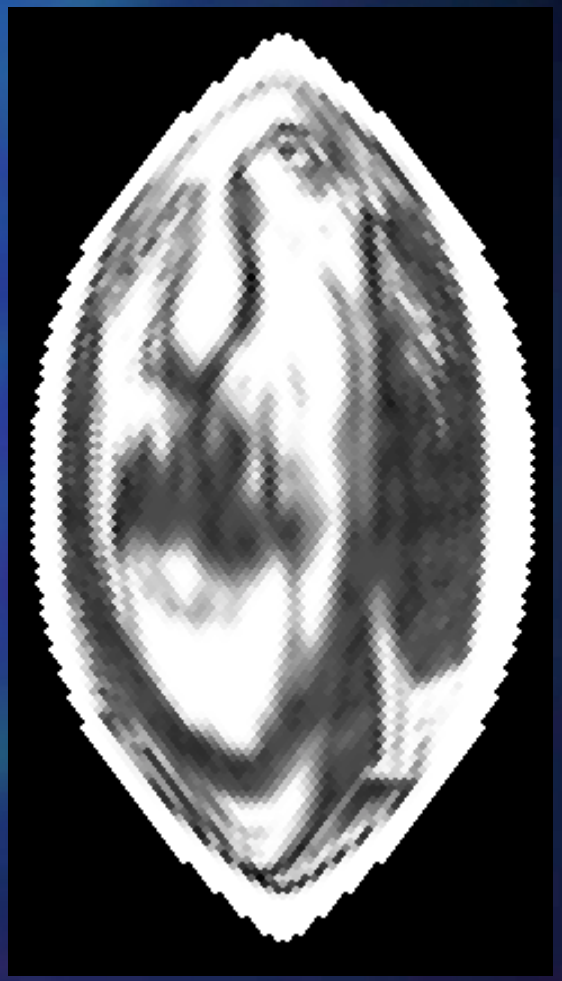




Insect Vision (B-EYE): Circles With Lines



Insect Vision (B-EYE): Bee and ??



How Is It Possible?

- Given their limitations, how do millions of Monarch butterflies manage to migrate across the continent to a small region in the mountains of Mexico?
- Given the existence of the migration, in what ways do Monarch butterflies differ from related, non-migratory, species?

Darwin's Argument

- Monarch butterflies have evolved a long distance, goal-oriented, migration
- The current migration developed about 12,000 years ago after the last ice age
- Monarch butterflies followed the northward expansion of their milkweed host plant
- However, 12,000 years is not enough time for major evolutionary changes

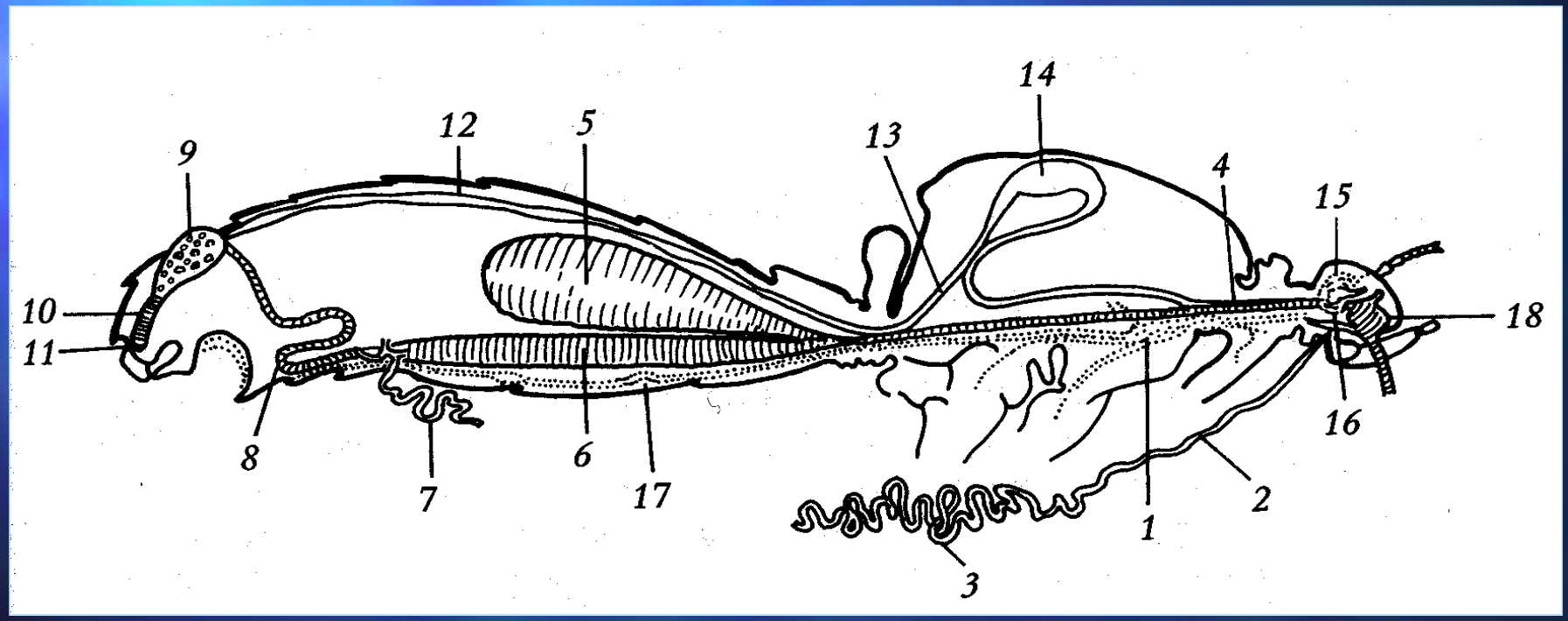
Darwin's Argument

- Therefore:
  - Current migration must have evolved from an earlier, simpler, migration
  - Morphology and physiology of Monarch butterflies will be similar to species with less spectacular migrations
  - Current migration has evolved primarily through small changes in flight behavior

Advantages of Monarch Butterfly Design (flight)

- Low gliding sink rate: 0.7 m/s;
  Monarch can use weak lift
- Small turning radius: 0.5 - 1.0 m;
  Monarch can center in narrow lift
- Water ballast: When low on lipid,
  can adjust CG for gliding and soaring

Advantages of Monarch Butterfly Design (ballast)



Advantages of Monarch Butterfly Design (navigation)

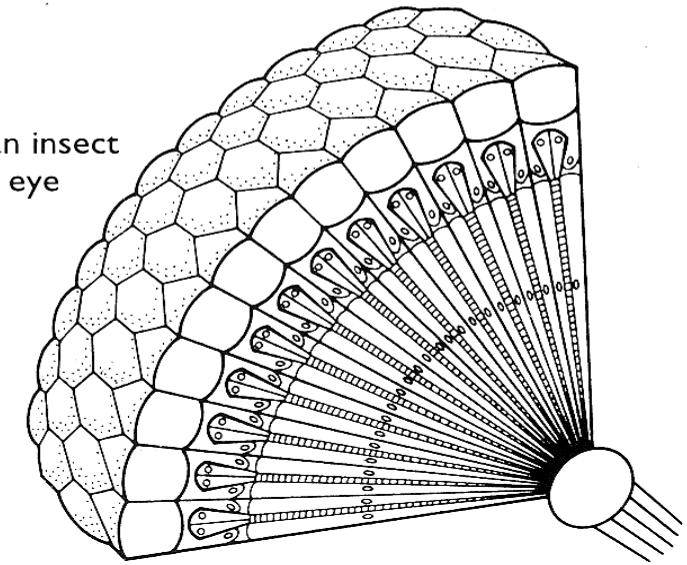
- Biological clock: Necessary for various methods of navigation
- Compound eyes
  - Polarized light
  - Ultraviolet light
  - Angles

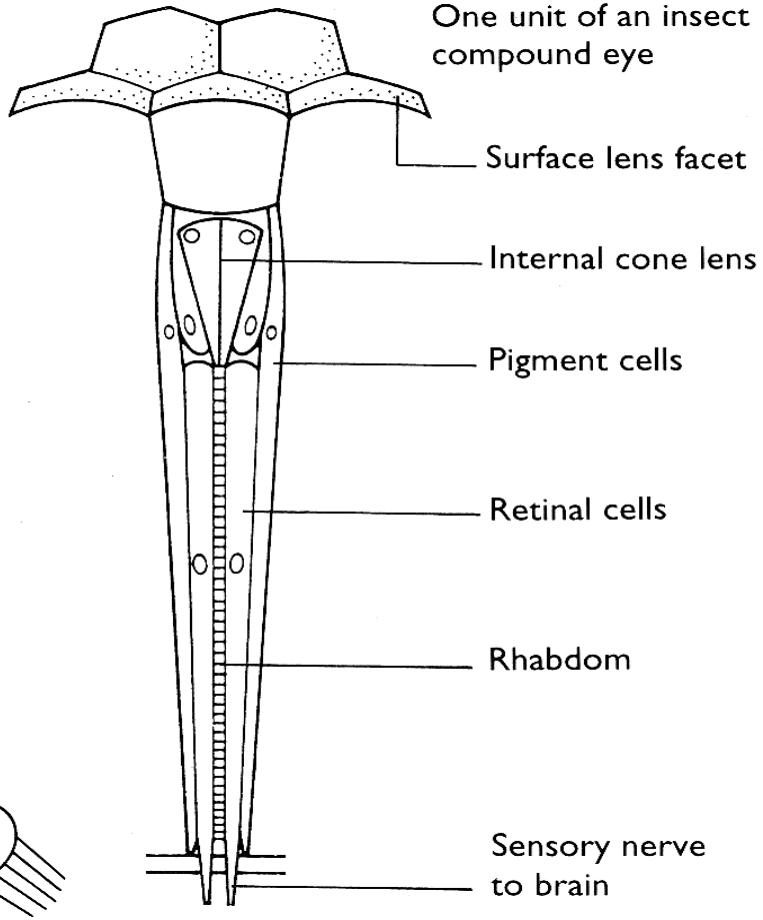
Advantages of the Insect Compound Eye

Advantages of the Insect Compound Eye

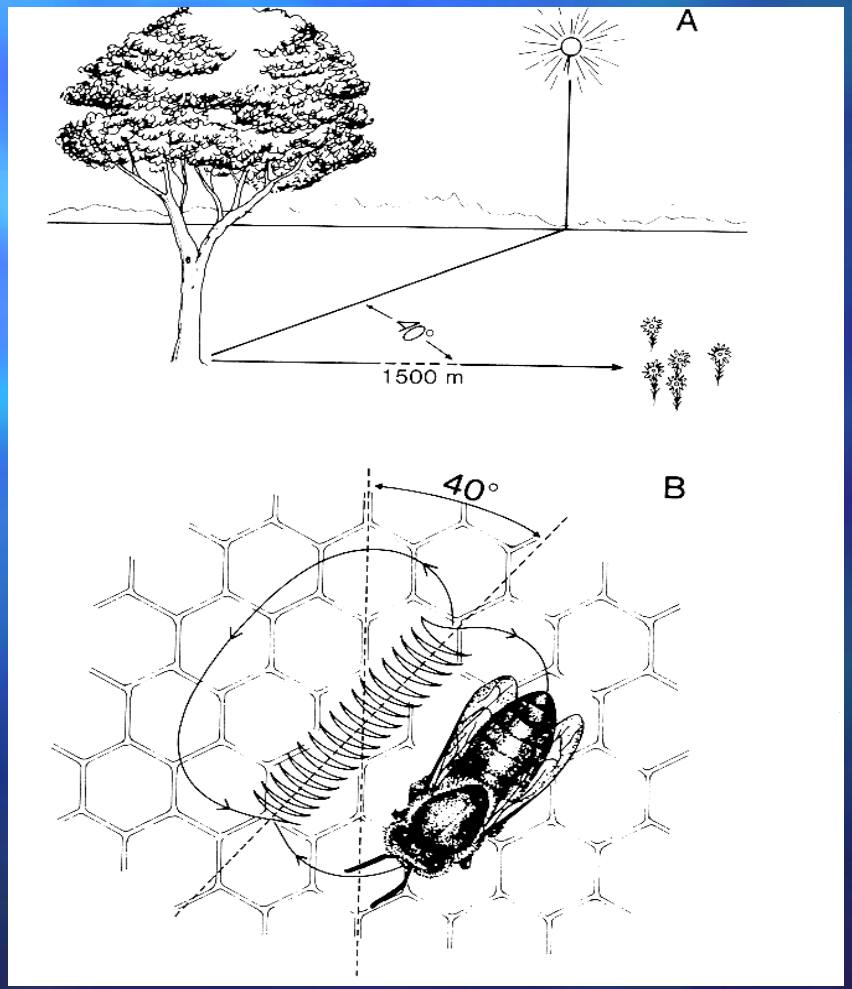
The compound eyes of insects are made up of hundreds of tubular elements, each with a facet at its outer face. The surface of the eye is thus a regular grid of these tiny facets, visible in this magnified image of a deer fly eye (*above*). Light passing through the facets is picked up by retinal cells in rods, or rhabdoms, at the base of each tube.

Sector of an insect compound eye





Advantages of the Insect Compound Eye



Advantages of Monarch Butterfly Design (navigation)

- Time compensated sun compass: Butterfly measures sun's azimuth and uses biological clock to correct course
  - Clear sky - Measure azimuth directly
  - Broken cloud - Use polarized light
  - In cloud - Use ultraviolet light

Advantages of Monarch Butterfly Design (navigation)

- Altitude angle detector:
  Butterfly measures solar AA at midday
  - Information on advance of seasons
  - Tracking a particular zone of AAs is an easy method to time movement across latitudes

Advantages of Monarch Butterfly Design (navigation)

- Magnetic field detector:
  Allows for
  - Approximation of latitude
  - Approximation of longitude
  - Measurement of true vertical movement
  - Measurement of true horizontal movement
  - Measurement of true airspeed

Advantages of Monarch Butterfly Design (general)

- Tough: Body can absorb large crushing, bending, and shearing forces
- Ectothermic (usually): Low energy use when resting, preserves lipid reserve
- Endothemic (rare) : Can generate sufficient heat to initiate flight at low ambient temperatures

Advantages of Monarch Butterfly Design (general)

- Poisonous: Can fly high and soar in thermals with insectivorous birds
- r strategist: Rapid population growth allows for quick recovery of numbers
- Reproductive diapause: Saves energy by postponing reproductive maturation

General Strategy for Monarch butterfly Migration

- Survive the Journey
- Act to make gains
- Never go back
- All gains must be cheaper than flying the same distance by cruising flight

Survive the Journey

General Strategy for Monarch butterfly Migration

- Survive the Journey
- Act to make gains
- Never go back
- All gains must be cheaper than flying the same distance by cruising flight

Flight Tactics: Great Circle Route

- Problem: To calculate a Great Circle route to the overwintering sites
- Reason: Monarchs need to be able to identify wind conditions
- Solution: Use magnetic sense to calculate specific magnetoclinic route that approximates GC route

Flight Tactics: Avoiding Gulf of Mexico

- Problem: To modify magnetoclinic route and avoid the Gulf of Mexico
- Reason: Monarchs in the southeast corner of the US face a long detour around the Gulf, often into headwinds
- Solution: Use magnetic sense to monitor latitude and alter magnetoclinic route to west well in advance of Gulf

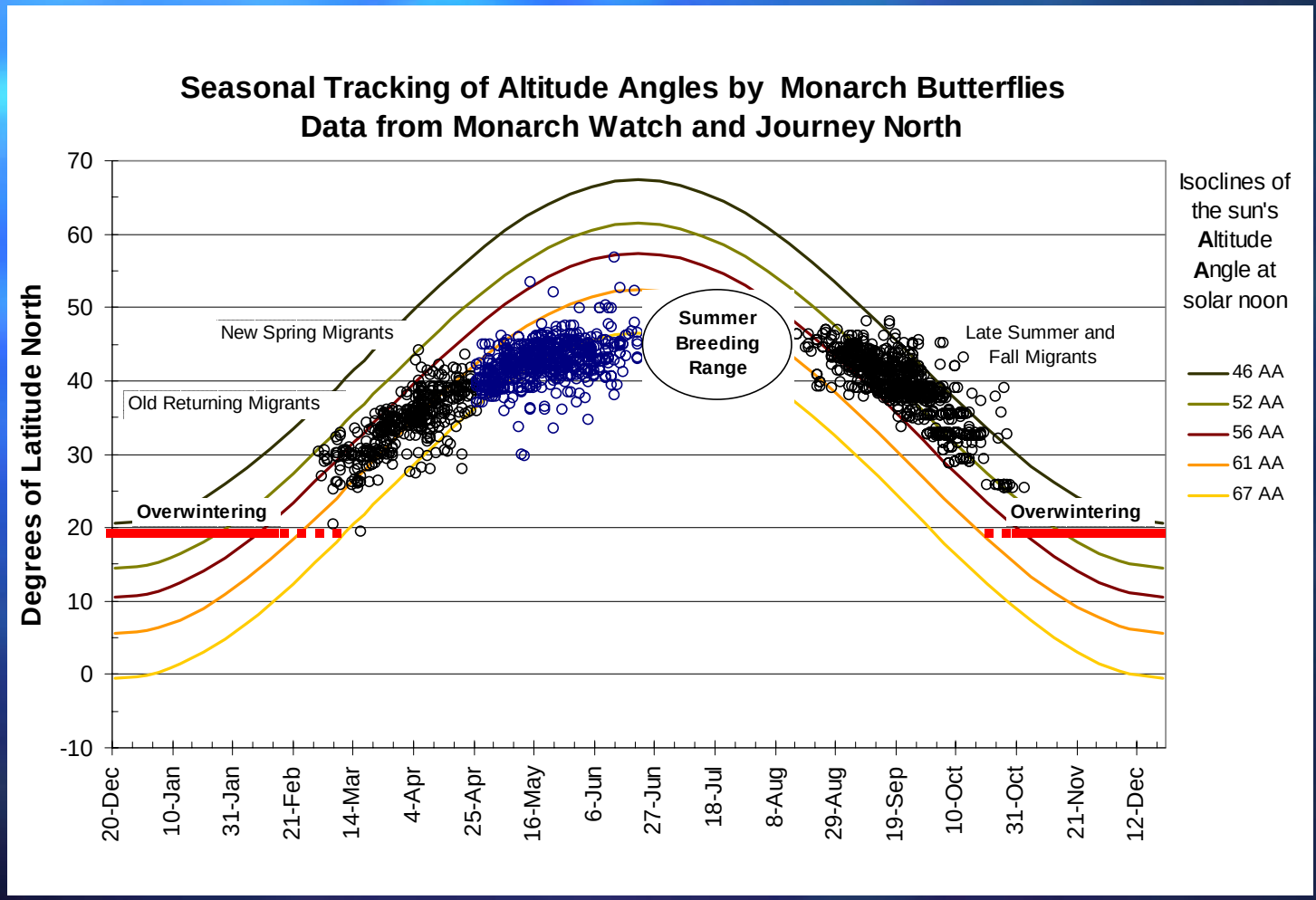
Flight Tactics: Escaping Northeast

- Problem: To manage a timely escape from the northeast without increasing the length of the journey to the OWS
- Reason: Weather is fast deteriorating and Monarchs can not wait around for subset of wind conditions favorable for making gains to the OWS
- Solution: Use all wind conditions that satisfy the strategy ‘Never go back’

Flight Tactics: Coordinating Migration

- Problem: To coordinate the migration across latitudes such that all Monarchs are moving through regions at the same time
- Reason: Each butterfly gains by hiding in the crowd; minimizes the chance of becoming a meal for local predators
- Solution: Entire population tracks specific AA's across continent to OWS

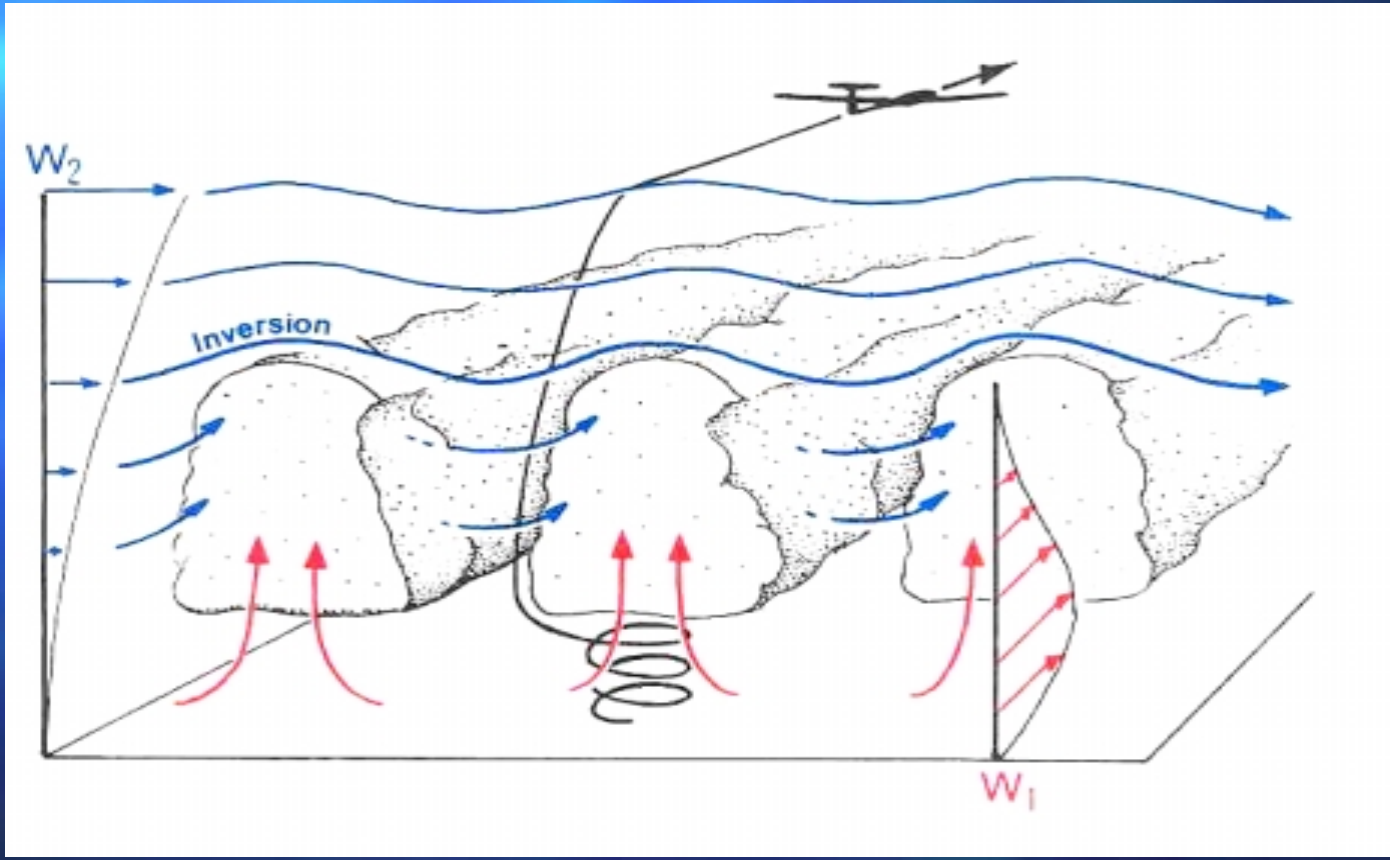
Flight Tactics: Coordinating Migration

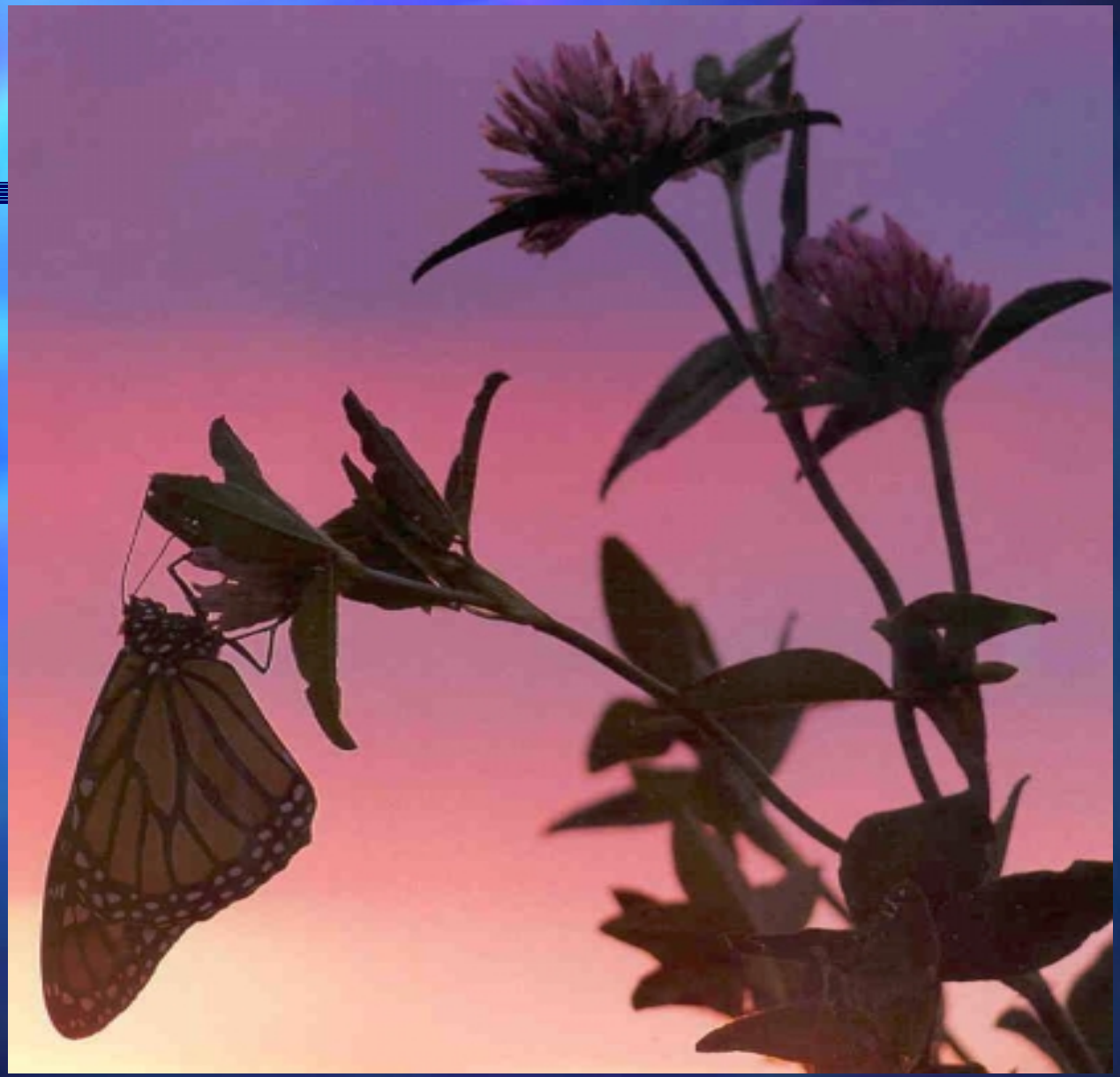


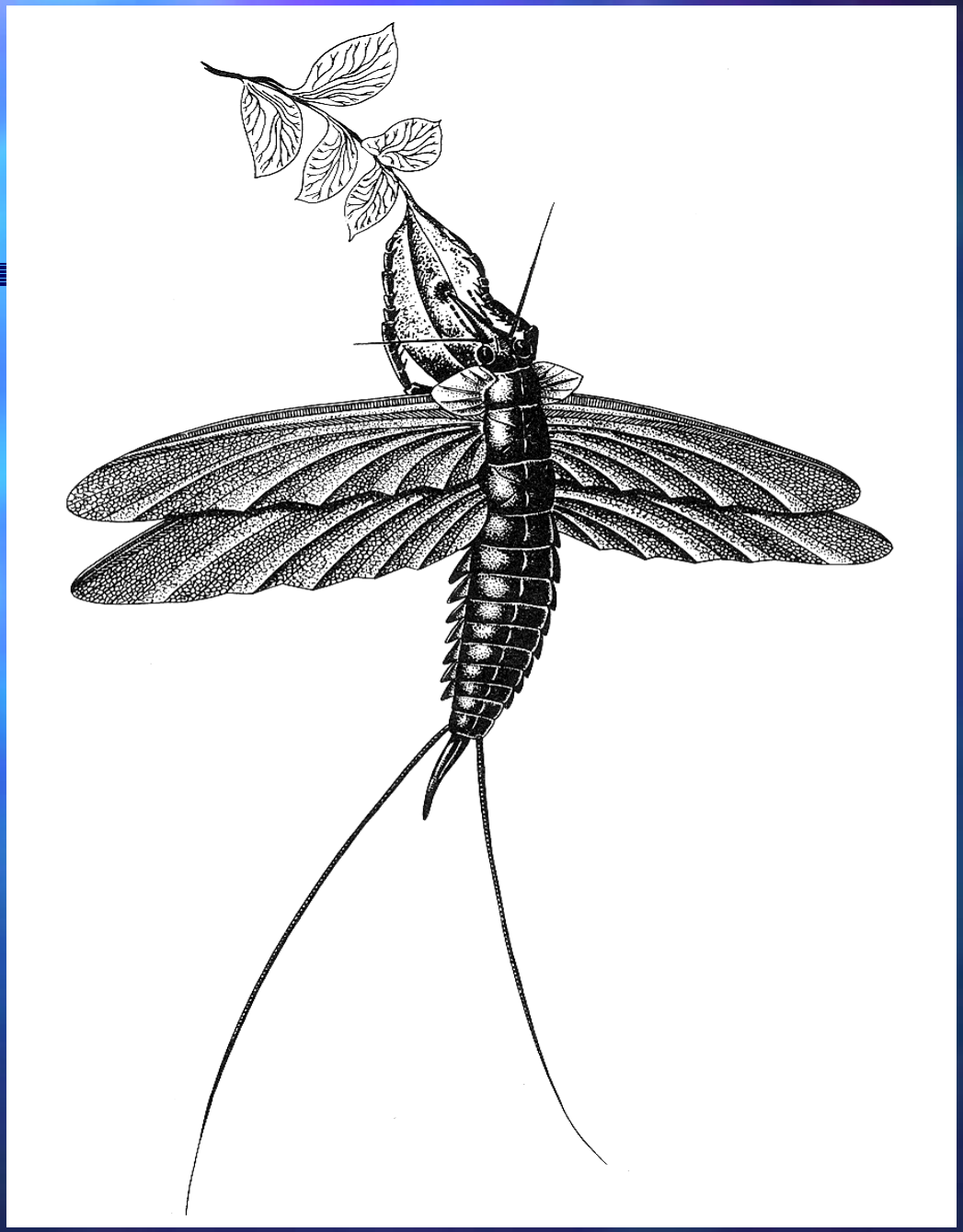
Flight Tactics: Getting An Early Start

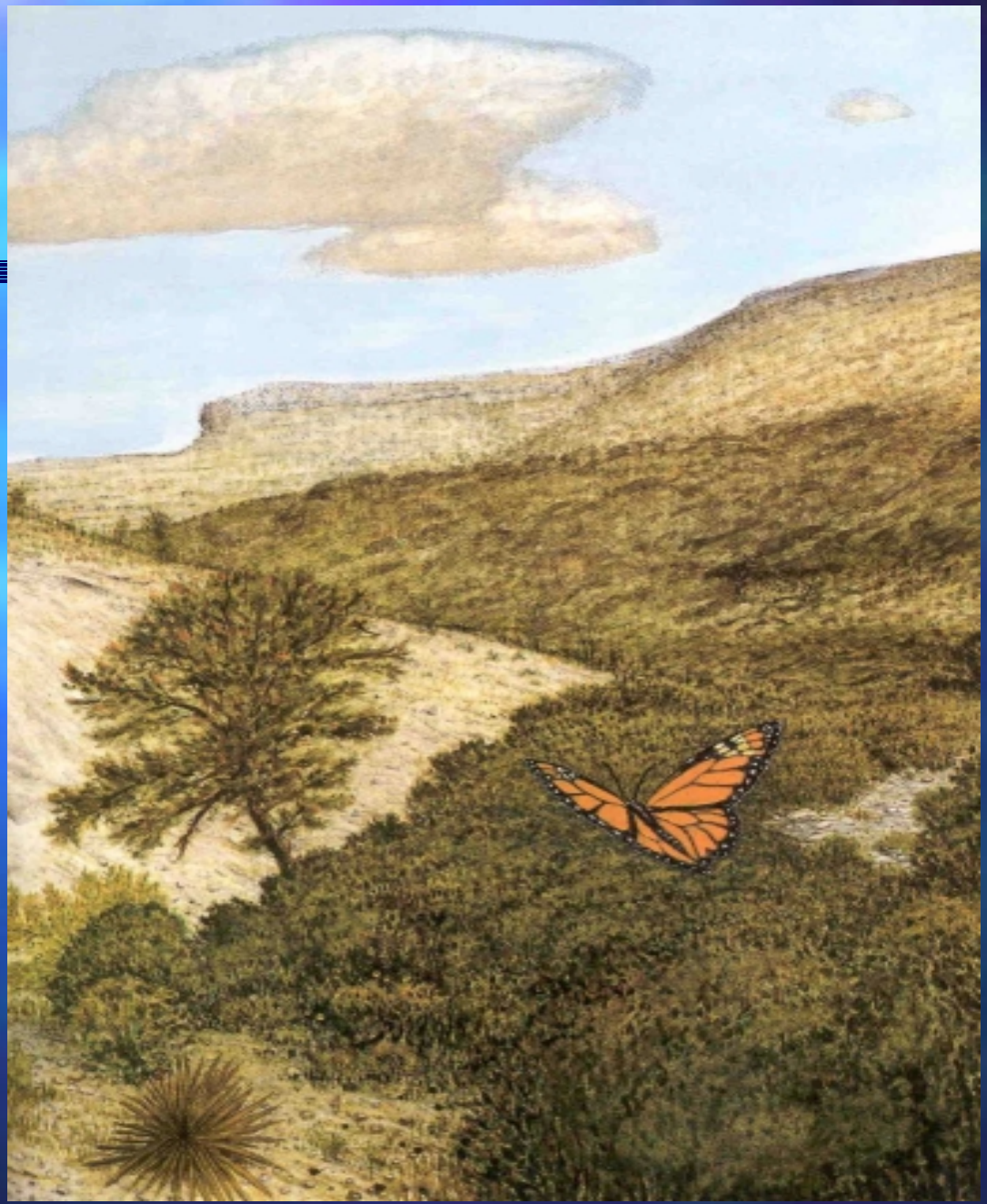
- Problem: To get an early start in the morning and not drain fuel reserve
- Reason: Can't waste time; Monarchs have to gain about 30 - 43 km per day to keep up with favorable zone of AAs
- Solution: Use shear waves at top of radiation inversion for early morning soaring flights

Flight Tactics:
Getting an Early Start









The Arena: North America

Possible Tactics For A Flying Biomorphic Explorer

- Wait for favorable wind conditions
- Check wind frequently
- Start exploring as soon as wind is favorable
- Avoid obstacles
- Take every opportunity to soar:
  Slope, thermal, or wave soaring

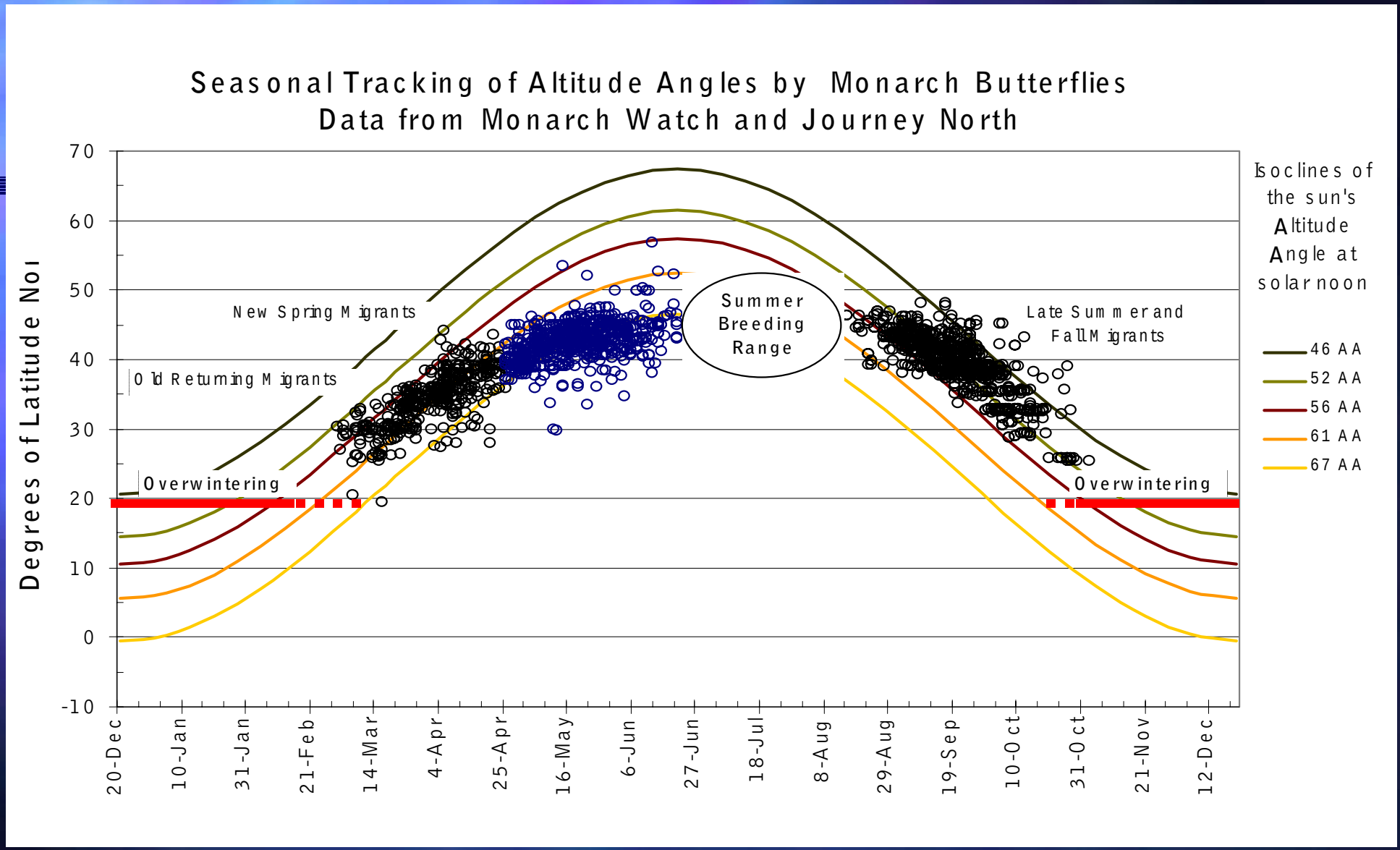
Possible Tactics For A Flying Biomorphic Explorer

- Monitor rate of progress towards goal
- If progress is negative, land (or park in lift) until conditions improve
- If progress is positive, check that cost of gains is below the critical threshold
- If cost exceeds threshold, land (or park) until conditions improve

Photo by Paul B. Southerland

Monarch Butterfly Migration

Monarch Butterfly Migration: Old Style Tags


Seasonal Tracking of Altitude Angles by Monarch Butterflies
Data from Monarch Watch and Journey North
Degrees of Latitude North
70
60
50
40
30
20
10
0
-10
20-Dec
10-Jan
31-Jan
21-Feb
14-Mar
4-Apr
25-Apr
16-May
6-Jun
27-Jun
18-Jul
8-Aug
29-Aug
19-Sep
10-Oct
31-Oct
21-Nov
12-Dec
New Spring Migrants
Old Returning Migrants
Overwintering
Summer Breeding Range
Late Summer and Fall Migrants
Overwintering
Isoclines of the sun's Altitude Angle at solar noon
46 AA
52 AA
56 AA
61 AA
67 AA